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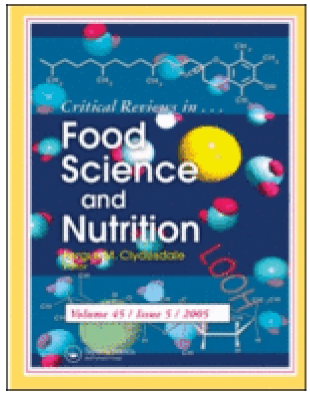

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Food applications of *Irvingia gabonensis* (Aubry-Lecomte ex. O'Rorke) Baill., the "wild mango": a review

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Abstract

Irvingia gabonensis, also known as 'wild mango' is a multipurpose fruit tree that is native to tropical Africa. It is recognized as a priority indigenous fruit tree in western and central Africa since its wood is used for making utensils and fruits are mostly used as food and medicinal. The fruit mesocarp contains various phytochemicals and a concentration of ascorbic acid higher than some vitamin C rich fruits then it is consumed fresh or dried or is used for the production of juice and wine or as a flavourant. The *I. gabonensis* fruit kernel is rich in oil (63%-69% crude fat), which is mainly composed of myristic and lauric acids. Moreover, the content of carbohydrates and protein is very high. Seeds can be dried and milled, and the cake obtained can be used directly or after degreasing as a thickener in 'ogbono soup'. The kernel fats are instead used as a pharmaceutical excipient as well as for margarine production. The objective of this work is to provide an update review of the available knowledge about the characteristics of the *I. gabonensis* fruit in order to evaluate its potential use in the food industry.

Keywords: bush mango, ogbono soup, dika nut, polyphenols, carotenoids

1. Introduction

Irvingia gabonensis (Aubry-Lecomte ex O'Rorke) Baill., also known as 'African mango tree', 'bush mango', 'sweet bush mango', 'wild mango', 'dika nut', 'rainy season bush mango', 'dika bread tree', 'odika', 'manguier sauvage', 'chocolatier', or 'ogbono', is a multipurpose fruit tree native to tropical Africa, and more specifically to Angola, Cameroon, Central African Republic, Congo, Cote d'Ivore, Democratic Republic of Congo, Equatorial Guinea, Gabon, Ghana, Guinea-Bissau, Liberia, Nigeria, Senegal, Sierra Leone, Sudan, and Uganda (National Research Council 2006; Singh 2007). This traditional tree is common in dense evergreen rain forests but is also found near riverbanks (Atangana et al. 2001); it has been reported to be used as a source of timber and to make utensils, and also as food and medicine (Okoronkwo et al. 2014; Fungo et al. 2016; Ofundem et al. 2017).

The fruits are available from May to September with the peak harvesting period being June/July (Onimawo et al. 2003). The fruit is a broad, ellipsoid drupe with a thin epicarp, an edible fleshy mesocarp (pulp) (when ripe) and a hard, stony, nut encasing a soft, oil rich, dicotyledonous kernel wrapped inside a brown seed-coat (Ogunsina, Koya and Adeosun 2008[a]; Ogunsina, Koya and Adeosun 2008[b]; Ogunsina et al. 2012; Ogunsina, Olatunde and Adeleye 2014). This kernel, which is also referred to as seed, is widely used as food (Omoniyi et al. 2017). Thus, *I. gabonensis* is included in the FAO/INFOODS biodiversity list and is recognized by the International Centre for Research in Agroforestry as a priority indigenous fruit tree for West and Central Africa (Franzel, Jaenicke and Janssen 1996; Leakey et al. 2005; National Research Council 2006; Ruth Charrondière et al. 2013; Stadlmayr et al. 2013; Vihotogbe´, van der Berg and Sosef 2013; Bvenura and Sivakumar 2017; Shaheen, Ahmad and Haroon 2017). Due to this, ethnobotanical and economical researches focussed on *I. gabonensis*, have emerged in recent years (Ladipo, Fondoun and Ganga 1996; Ayuk et al. 1999; Leakey et al. 2000; Atangana et al. 2001; Leakey and Page 2006; Singh 2007; Vihotogbé, van der

Berg and Sosef 2013); however, up until now, a comprehensive review summarising its applications and the functional properties of *I. gabonensis* products in the food industry is lacking. The aim of this review is thus to deepen the existing knowledge about the physico-chemical characteristics of *I. gabonensis* pulp and kernels in order to verify their potential use in the food industry, especially in functional products.

2. Fruits

The fresh fruits, that are similar to small mangoes, have a green-yellow colour and since their taste varies between sweet and bitter they are divided into two groups, the "eating type" and the "cooking type. The "eating type" comprises of the species *Irvingia gabonensis* which is fibrous, has a mesocarp characterized by a sweet taste and is a yellow to orange colour while the "cooking type" is the *Irvingia wombolu* species whose seeds are widely processed across West Africa but the mesocarp is bitter and non-edible (Harris 1996).

The pulp of *I. gabonensis* has an elevated moisture content (Table 1), from 78.8% to 90.47%, and a soluble solid content of around 10%, which indicates that this fruit is suitable for juice production. The pH varies between 4.7 to 5.8 and acidity may be the reason behind the bitter taste of the pulp (Onimawo et al. 2003). The ash content is low (0.8 – 1.8 %) but potassium (1114 mg/100 g dry weight) and calcium (118 mg/100 g dry weight) contents are high in contrast to low sodium content (12 mg/100 g dry weight) (Olayiwola et al. 2013). The high variability on reported fat content of this fruit is due to the differences in sample extraction amongst different studies.

I. gabonensis fruits are well cited as antisickling products (Amujoyegbe et al. 2016). Etebu (2012) compared the phytochemicals in *I. gabonensis* and *I. wombolu* documenting the presence of five groups of phytochemicals (alkaloids, flavonoids, saponins, tannins and glucosides) in mesocarp from both varieties. This finding is supported by other studies which investigated these components (Table 2). The fruit of *I. gabonensis* can be considered vitamin C rich (51-76 mg/100g) when compared with other fruits like orange (about 50 mg/100g), and common mango (about 40 mg/100g) (USDA 2018). Also, the carotenoid and the phenolic content of *I. gabonensis* fruits are very high (Table 2). Emejulo et al. (2014) studied the effect of *I. gabonensis* fruit juice on serum lipid profile of sodium fluoride-intoxicated rats by comparing with positive and negative control groups. They concluded that the level of HDL-cholesterol was higher in the *I. gabonensis* group than in the positive control group (20 mg/kg body weight of quercertin + 100 mg/kg body weight of alfa-tocopherol) and the fruit juice of *I. gabonensis* was reported to have a lowering effect on LDL-cholesterol as compared to the other groups tested. The author attributed this action to the presence of alkaloids, saponins, flavonoids and polyphenols commonly known to reduce serum lipids in animals (Ezekwe and Obioha 2001). An ameliorative effect was observed in NaF-induced lipidemia in rats when fed with *I. gabonensis* fruit juice, which may be due to its reportedly rich vitamin C content and plant polyphenols. *I. gabonensis* pulp is also used for diabetes treatment when coupled with *Ouratea turnarea* (Kuete and Efferth 2011).

As *I. gabonensis* kernels are more economically resourceful, the traditional post-harvesting operations aim to remove the kernel in its optimum conditions. In most cases, the interest in the seed results in the neglect of the potential of other parts of the fruit, including the pulp.

Fruit harvesting must be undertaken at an appropriate time, preventing the harvest of immature fruits, but also ensuring a good shelf life (Ladipo 1999). Besides harvesting, the gathering of fallen ripe fruits by women, children and young adults in many of the cultivated areas has also been reported (Elah 2010; Nkwatoh et al. 2010). The fresh fruits of *I. gabonensis* have a shelf life of less than 2 days if picked when ripe and not more than 10 days if harvested at the mature green stage, due to high respiration rate, moisture loss and microbial attack (Aina 1990; Joseph and Aworth 1991; Joseph and Aworth 1992; Etebu 2013). Etebu (2013) isolated four genera of fungi (*Aspergillus, Penicillium, Rhizopus* and *Mucor*) from postharvest fruits of *I. gabonensis* and *I. wombolu*, concluding that *Rhizopus* and *Mucor* species were the most predominant genera of fungi associated with postharvest *Irvingia* fruits.

Aina (1990) described the physicochemical changes in *I. gabonensis* fruits during normal storage ripening and revealed that, with the ripening process, the fruit peel gets yellow and the sweetness of the pulp increases due to starch degradation. The sourness and the acidity decreases, the fruit turns softer, mainly due to pectin degradation, and, finally, the vitamin C content decreases as ascorbic acid is very susceptible to oxidative degradation. In order to extend the shelf-life of *I. gabonensis* fruits during storage, Joseph and Aworh (1991; 1992) studied the influence of some post-harvest treatments. Firstly, while comparing ripening at room temperature and refrigerated storage of the fruits, it was noticed that low temperatures induced cold injuries in *I. gabonensis* and that room-ripened fruits had better flesh colour and texture, although, they also had a higher moisture loss (Joseph and Aworh 1991). After these primary results, the authors conducted other experiments in order to determine the effects of dipping fruits in hot water and in different concentrations of benomyl, DHA-S, and $Na_2S_20_5$ at different temperatures, on the shelf life and quality. While untreated fruits had become brownish black and unmarketable by day 12, the fruits treated with hot 0.1% benomyl or 0.5% $Na_2S_20_5$ followed by waxing had an attractive appearance and good quality until day 14. Dipping fruits in hot water (55 °C) or chemical solutions (0.1% benomyl, 0.5% DHA-S or 0-5% $Na_2S_20_5$) followed by waxing or packaging in boxes overwrapped with stretch PVC film, delayed ripening, controlled decay, minimised weight loss and extended the shelf life of the fruits under tropical ambient conditions, without adverse effects on visual and chemical qualities (Joseph and Aworh 1992).

I. gabonensis pulp is consumed to a considerable extent, normally eaten raw as a dessert or snack; however, large quantities are usually wasted (Akubor 1996). Juice, beverage, and jam manufacturing requires little processing and addresses the need to use the raw pulp, injured or not. Various authors cited bush mango as being more suitable for juice, wine, and jam production, compared to other known tropical fruits (Ejiofor 1994; Okolo 1994; Agbor 1994; Okafor, Okolo and Ejiofor 1996; Akubor 1996; Ainge and Brown 2001; Aworh 2015).

Laboratory trials have shown that jam can be produced from lesser known Nigerian fruits including *I. gabonensis* (Aina and Adesina 1991; Ainge and Brown 2001; Aworh 2014; Aworh 2015). Aworh

(2014) produced jams from three indigenous fruits containing 50% of pulp. For the *I. gabonensis* jam recipe, 500 g of pulp was mashed and boiled with 638 g of sugar, 100 g of water, 6 g of citric acid and 5 g of calcium chloride in a steam-jacketed kettle. In a sensory evaluation of the wild fruit jams, *I. gabonensis* jam was the less preferred, especially in terms of flavour and consistency. The author concluded that although *I. gabonensis* jam is manufacturable, it may not be marketable for its low acceptance.

Akubor (1996) studied the suitability of *I. gabonensis* fruits for juice and wine production. The pulp was blended with water in a 1:5 proportion, then filtered in cheesecloth and cane sugar added in order to obtain 23 ºBrix. A yield of 75% was achieved and the obtained juice was compared to other tropical fruit juices obtained from banana, orange and cashew. No differences were observed among these juices and the *I. gabonensis* juice showed only a lower protein content and a higher ascorbic acid content compared to the other tropical fruit juices.

For wine production, the *I. gabonensis* juice was fermented with *Saccharomyces cerevisiae* at 30 °C for 28 days. The wine produced had 8.12% (v/v) alcohol, 0.78% protein, 6.5 °Brix SS, and a pH 3.10. Consumer test showed that the obtained product was generally accepted and had no significant differences in colour, sweetness, mouthfeel, and general acceptability as compared to a German reference wine.

Besides beverage production, osmotic dehydration has also been cited as an excellent application of *I. gabonensis* fruits (Falade and Aworh 2004; Falade and Aworh 2005; Aworh 2015). With this process, a variety of new shelf-stable food products can be developed with few modifications in the fruits' colour, flavour, and texture characteristics. Osmose-dried products could reduce perishable fruit losses postharvest and ensure that seasonal fruit products are available throughout the year. The osmotic process is very suitable as a pre-treatment prior to air-drying of fruits, resulting in a fruit product with an intermediate moisture content (Falade and Aworh 2004; Falade and Aworh 2005; Aworh 2015).

Falade and Aworh (2004) studied the influence of osmotic pre-treatment on the adsorption isotherms of osmo-air dried *I. gabonensis* fruits. The treatments were performed at 27 ºC and 40 ºC, with sugar concentrations of 52 ºBrix, 60 ºBrix and 68 ºBrix, maintaining a fruit:syrup ratio of 1:4 w/w for 10 h. Afterwards the fruit slices were oven air-dried at 60 ºC for 72 h. The authors concluded that the adsorption isotherms of osmo-oven dried fruits followed a type III isotherm, which characterizes high sugar products like many other fruits. In the experiments, *I. gabonensis* isotherm was affected by fruit ripeness degree. In fact, the equilibrium moisture content of the fruit increased with higher degree of ripeness at the same water activity (a_w), concentration of the sucrose solution used for pre-treatment (the higher the sugar concentration, less water was absorbed at low and intermediate a_w ranges), and equilibrium temperature (equilibrium moisture content decreased with increasing temperature, when $a_w < 0.8$).

Dried fruits of *I. gabonensis* can also be used as a flavouring agent in other food products in order to diversify its usage. Mbaeyi and Anyanwu (2010) evaluated the use of these products as a yogurt flavourant. The dried and pliable fruits were milled, sieved through a 0.59 mm sieve, and added at 0.8%, 1.6%, 2.4%, 3.2%, 4.0%, and 4.8% in commercial full-fat cow yogurt. The best sensory results were obtained in the yogurt containing 0.8% of dried fruit with an overall acceptability statistically not different from commercial yogurt.

3. Seeds

The kernels are the main products of *I. gabonensis* and constitute an important part of West and Central Africa diet, mainly in rural communities, providing carbohydrate and protein. The seed consists of a hard shell, an outer brown testa (hull) and inside, the kernel, composed of two white cotyledons. The seeds of the fruits of *I. gabonensis*, can be eaten raw or roasted and are used in food preparations (National Research Council, 2006).

180 The summary of the proximate composition of *I. gabonensis* kernels is provided in Table 3.
181 According to literature, *I. gabonensis* seed has a high energetic value (595 – 729 kcal), due to high
182 percentages of fat (10 – 72%), carbohydrates (3 - 52%) and protein (7-22%). With crude protein
183 content ranging from 7 to 22%, *I. gabonensis* seeds have comparable or higher protein levels than the
184 majority of the cereals comprising our daily diet (corn, sorghum, rice, etc), which generally does not
185 exceed 13%. Fibre content was generally low in the studies reported, except by Onimawo et al.
186 (2003), who observed an outlying value of 10.23%. This may be due to sample preparation and/or
187 plant origin.

188 The analysis revealed that *I. gabonensis* is essentially a rich source of edible fat, with a mean
189 percentage of 61.56%. Some oil-bearing products with such high percentage of oil are coconut,
190 almond, pistachio, sunflower, walnut, and watermelon seeds which contain 62.3, 58.9, 53.5, 52.1,
191 64.5 and 52.6% of oil, respectively (Gopalan, Rama Sari and Balasubramanian 2014).

192 This oilseed is a good source of minerals, especially phosphate and chloride, and is therefore
193 recommended for use in the diets of individuals with low levels of these cations and anions.

194 Acid value is used as an indicator for edibility of oil and suitability for use in the paint industry (Etong
195 et al., 2014). The acid value for samples of *I. gabonensis* oil found in literature (3.18 - 24.7 mg
196 KOH/g) were considerably diverse, and most of them did not fall within the allowable limits for
197 edible oils, 4.0 mg KOH/g fat for oil (Codex Alimentarius 2015). The free fatty acid values ranged
198 from 0.30 to 4.70%, which can be considered low if compared with other vegetable oils (Omoniyi et
199 al. 2017). Etong, Mustapha and Taleat (2014) reported that a low acid value with a correspondingly
200 low level of free fatty acid, suggests the low level of hydrolytic and lipolytic activities in the oil, thus
201 the seed oil studied could be a good source of raw materials for industries. The peroxide value (0.04
202 – 3.33 meq O_2/kg fat) was incredibly low, characterizing *I. gabonensis* fat as a fresh oil as it has a
203 peroxide value lower than 10 meq/kg (Codex Alimentarius 2015). Low peroxide values indicate a
204 low level of oxidative rancidity and also suggests a high antioxidant level in the oil (Etong, Mustapha
205 and Taleat 2014). Etong, Mustapha and Taleat (2014) also stated that the relative low iodine number

of the seed oil may be indicative of the presence of few unsaturated bonds and low susceptibility to oxidative rancidity. High saponification value (187.90 – 701.00 mg KOH/g) also indicates it has potential for industrial use (Omoniyi et al. 2017). Low unsaponifiable matter (0.12 – 1.70%) indicates that the oil is pure (Etong, Mustapha and Taleat 2014).

I. gabonensis seed kernel oil (Table 6) is mostly cited as a mystiric-lauric oil, with mystiric acid being the most abundant followed by lauric acid (Matos et al. 2009; Silou et al. 2011; Yamoneka et al. 2015; Lieb et al. 2018). Nine free fatty acids were described in literature, only three of which are unsaturated.

Amongst triacylglicerols the most abundant are LaMM (31.1%), CMM/LaLaM (25.6%) and MMM/LaMP (12.9%) (Lieb et al. 2018). Similar results were reported by Silou et al. (2011) and Yamoneka et al. (2015).

According to Matos et al. (2009), *I. gabonensis* kernel oil is a technical fat because it resists thermo oxidative, hydrolytic, and enzymatic activities due to its fatty acid profile.

In-vivo and *in-vitro* assays have already been developed to functionally characterize the seed. Data comprising of the antioxidant activity, total phenol (TPC), total flavonoid (TFC), total anthocyanin (TAC) and total tannin (TTC) contents, as well as total carotenoid (TCC) and ascorbic acid contents, are described in Table 7.

The presence of steroids, flavonoids, alkaloids, cardiac glycosides, volatile oils, terpenoids, tannins and saponins in *I. gabonensis* kernel extract has been revealed on phytochemical screening by Obianime and Uche (2010).

Giami, Okonkwo and Akusu (1994) studied the influence of heat treatment in the composition of *I. gabonensis* seed flour and stated that increase in temperature occasioned an undesired loss in ascorbic acid, total carotenoid and total polyphenol contents.

I. gabonensis seed phytochemical constituents were also compared with mango (*Mangifera indica*) kernels and with a mix of both species (Arogba and Omede 2012; Arogba 2014). According to DPPH, lipid peroxidation and FRAP assays, mango kernels had a higher antioxidant activity than *I.*

gabonensis kernels, contrary to nitric oxide assay results. However, *I. gabonensis* kernel results were similar or higher than mango kernel for ascorbic acid content. Total phenol, flavonoid and tannin contents were also higher in *Mangifera indica* samples, whereas, *I. gabonensis* kernels presented a much higher anthocyanin content. The mix of kernels presented higher total phenol and tannin contents than individual samples of mango and *I. gabonensis*. The author showed in these studies that processed kernels of mango (*Mangifera indica*) and *I. gabonensis* contain significant amounts of gallotannins with high antioxidant capacity even with statistically ($p < 0.05$) higher activity than some other known naturally-occurring phenolic antioxidants (Arogba and Omede 2012; Arogba 2014).

I. gabonensis kernel was also compared to 13 Cameroonian herbs/spices. It presented the highest FRAP-free antioxidant capacity followed by *Thymus vulgaris* and ranked third in FRAP total antioxidant but had one of the lowest results in Folin total antioxidant assay (Agbor et al. 2005).

Obianime and Uche (2010) studied the effects of *I. gabonensis* seed phytoconstituents in an *in vivo* study, which described the influence of aqueous extract of *I. gabonensis* kernels on biochemical parameters of adult male guinea pigs. The animals were divided into groups in order to perform time-dependent and dose-dependent studies. Groups 1-5 were administered a fixed dose of *I. gabonensis* extract (400 mg/kg/day) over a period of 7, 14, 21, 28 days, respectively. Groups 6-10 were administered different doses of the extract (50-400 mg/kg/day) for 96 hours. Results showed that the aqueous extract of *I. gabonensis* kernels caused a dose and time-dependent decrease in urea, uric acid, creatine, total cholesterol, protein, alkaline acid, and prostatic phosphatases. Pre-treatment with *I. gabonensis* was also able to inhibit the increase in most biochemical parameter levels caused by cadmium administration. The highest reduction effect was obtained with uric acid at 400 mg/kg of *I. gabonensis* extract while the least effect was observed in total cholesterol (Obianime and Uche, 2010).

I. gabonensis seed extracts were also evaluated for obesity management (Ngondi, Oben and Minka 2005). The subjects ingested three capsules, three times daily, each containing 350 mg of *I. gabonensis* seed extract (active formulation) or oat bran (placebo), for one month. After 4 weeks, the mean body weight of the *I. gabonensis* group had decreased by 5.26% and that of the placebo group by 1.32%. By the second week, the systolic blood pressure was significantly reduced by the active extract. Obese patients under *I. gabonensis* treatment also had a reduction of 39.21% in total cholesterol, 44.9% in triglycerides, 45.58% in LDL and 32.36% in blood glucose level, as well as an increase of 46.85% in HDL-cholesterol.

Dosumu et al. (2012) studied more specifically the antimicrobial effect of three Nigerian condiments, including *I. gabonensis* dried seed extracts. Clinical isolates of bacteria strains (*Staphylococcus aureus, Escherichia coli, Bacillus subtilis, Pseudomonas aeruginosa, Klebsiella pneumonae, Salmonella typhi*) and fungi (*Candida albicans, Aspergillus niger, Rhizopus stolon, Penicillum notatum, Tricophyton rubrum, Epidermophyton floccosum*) were used in the study. All extracts had higher anti-fungal but lower antibacterial activities. *I. gabonensis* seed extracts obtained with ethyl acetate (200 mg/ml) and methanol (200 mg/ml) presented considerable fungal inhibition when compared to the positive control (Tioconazole,10 μg/ml).

The first step in processing *I. gabonensis* kernels is separating the seeds from the mesocarp, using three principal methods for this operation: "Fresh Cracking"; "Wet Cracking" and "Dry Cracking". The "Fresh Cracking" method was reported by Ayuk et al. (1999) and Nkwatoh et al. (2010), in which the whole ripe fruit (pulp and seed) is split in half, through its natural longitudinal line of weakness, with a cutlass or sharp knife. On the other hand, for the other methods, *I. gabonensis* fruits are piled up in heaps and left to fermentate before seed extraction, which facilitates this operation. After fermentation, the seeds can be sun-dried ("Dry Cracking") or directly split ("Wet Cracking"), using truncheons or hard stones as helping tools (Ejiofor, Onwubuke and Okafor 1987; Ladipo, Fondoun and Ganga 1996; Ladipo 1999; Ogunsina, Koya and Adeosun 2008[a]). As soon as the seeds are cracked, the kernels wrapped in a dark brown testa are exposed and extracted with a knife (Ladipo 1999). The nut cracking process is, therefore, complicated and the dried kernel-in-shell is brittle, resulting in a large percentage of cotyledons being crushed during the process, thereby reducing the market value of the kernels (Ogunsina, Koya and Adeosun 2008[a]; Ogunsina, Koya and Adeosun 2008[b]).

Ogunsina, Koya and Adeosun (2008[a] and 2008[b]) investigated fracture behaviour of *I. gabonensis* seed in order to provide baseline data for designing an appropriate nutcracker. The physical analysis revealed that minimum toughness was required for nutshell fracture with the small size nuts loaded along the transverse axis. Furthermore, a machine, whose fracture mechanism was based on the deformation characteristics of dried *I. gabonensis* seeds under uni-axial compression, was fabricated. The experimental machine gave 100% cracking efficiency but with 24% kernel breakage in cracking sun-dried *I. gabonensis* seeds with 6.6% moisture content (w.b.). The machine provides a viable and effective technique for safe *I. gabonensis* kernel extraction. Orhevba et al. (2013) also studied physical and mechanical parameters of *I. gabonensis* seed cracking and the influence of moisture content (13.75% and 8.74%). The two moisture content levels were observed to be the range between which *I. gabonensis* kernels can be extracted with least percentage of crushing. Further decrease in the moisture content will make the kernel brittle, while a higher moisture level will make the kernel to stick to the shell, therefore, resulting in crushing during cracking. A motorized machine that is capable of multiple cracking of dika nuts was designed, fabricated and tested by Ogundahunsi, Ogunsina and Ibrahim (2016). The device utilizes the impact of a sliding hammer block falling from a height to crack a tray of 20 nuts; cracking and splitting them, liberating the embedded kernels as split cotyledons. The highest cracking efficiency and throughput values (72% and 12.86 kg/h, respectively) were obtained for big roasted nuts. The method of pre-treatment and dika nut sizes were found to affect the cracking efficiency and throughput of the motorized dika nut cracking machine. After being removed, the kernels are dried for 2 to 7 days, in the sun or on bamboo drying racks over the fireplace (Tchoundjeu, Atangana and Degrande 2005), in order to remove all moisture (Onimawo et al. 2003; Nkwatoh et al. 2010). This procedure guarantees the quality of the product during storage, by preventing it from discolouring and from fungal degradation (Ladipo 1999; Ainge and Brown 2001).

309 Fermentation helps to increase the protein and nitrogen-free extractives of the seeds, as well as to
310 reduce the fat content, which is an advantage if the kernels are consumed integrally (Ekpe, Umoh and
311 Eka 2007; Ekundayo, Oladipupo and Ekundayo 2013). Otherwise, if seeds proceed to further
312 processing, the fat loss may be undesired.

313 At this point, the kernels can be marketed or subjected to further processing. The cotyledons, without
314 the hull, are pounded with a mortar and pestle (Ekpe, Umoh and Eka 2007). The kernels can also be
315 milled with a grinding machine (Onimawo et al. 2003), which is a more industrial option (Festus and
316 Ibor 2014). The mash, called 'cake', is then moulded manually into convenient sizes and shapes,
317 placed in bags or leaves and smoke dried for a few days over a fireplace (Ekpe, Umoh and Eka 2007;
318 Caspa et al. 2015).

319 *I. gabonensis* cake can become too slimy over time because of its high fat content; therefore, for an
320 extended shelf-life, deffating is needed (Ainge and Brown 2001; Festus and Ibor 2014). This
321 operation yields, besides crude fat, defatted cake as a product, which, according to Ejiofor, Onwubuke
322 and Okafor (1987), is still acceptable in terms of its colour, taste, texture, and drawability after 9
323 months of storage under ambient conditions, and is more viscous, with greater emulsifying properties
324 than regular flour. The normal flour and defatted flour from *I. gabonensis* kernels are used as
325 ingredients for the popular Ogbono or draw soup which imparts unique flavour, drawability, and
326 thickening properties to the stew (Agbor 1994; Leakey and Newton 1994, Vivien and Faure 1996),
327 and also as 'dika bread' after being baked (Leakey et al. 2005). Ogbono soup is one of the cheapest,
328 easiest, and fastest Nigerian soups to prepare (Oktay and Sadıkoglu 2018). Onabanjo and Oguntona
329 (2003) described the following recipe as the most representative of this dish: *I. gabonensis* nuts, bitter
330 (*Vernonia amygdalina*) leaves and okro (*Hibiscus esculentus*) cooked with dried fish, crayfish,
331 ground pepper, pepper, palm oil, bouillon cubes, salt, and water. The influence of *I. gabonensis* seed
332 flour fat content and time of storage on the sensory characteristics of the Ogbono soup was evaluated.
333 Sensory parameters of sliminess (viscosity), taste, aroma, colour, and overall acceptability showed
334 that soups prepared from partially defatted *I. gabonensis* seed flour samples (especially the samples

with 9% and 12% fat) were more acceptable to the panellists than soups prepared from full-fat *I. gabonensis* seed flour (Idowu et al. 2013). The preference test carried out by Idowu et al. (2013) during the 12-week period of storage also showed that sliminess, colour, taste, aroma, and overall acceptability of Ogbono soups prepared from defatted *I. gabonensis* seed flour (12% and 9% fat) samples packaged in low- and high-density polyethylene films were all acceptable to the panellists. However, the full-fat flour had its sensory parameters significantly decreased in a period of 4 weeks (Akusu and Kiin-Kabari 2013; Idowu et al. 2013).

The defatted cake can also be extruded and moulded into Ogbono cubes, which are sold as a convenient cooking ingredient, used as thickeners in Ogbono soup (Okafor, Okolo and Ejiofor 1996; Ejiofor and Okafor 1997). Bamidele, Ojedokun and Fasogbon (2015) and Kiin-Kabari and Akusu (2017) developed and analysed a "ready-to-cook" powder mix (*I. gabonensis* seed powder, crayfish, stock fish, Ugwu, mixture of locust bean, onion mix, seasoning, and Cameroon powder) for Ogbono soup. Five formulations of instant Ogbono premix were evaluated by Bamidele, Ojedokun and Fasogbon (2015) (proximate composition, functional properties, micronutrients and sensory analysis). Moisture, protein and carbohydrate contents increased as *I. gabonensis* seed powder percentage decreased in formulations, inversely to fat content. Sensory evaluation showed that the samples with higher percentage of *I. gabonensis* seed powder rated the highest on overall acceptability based on the fact that they showed the real attribute of Ogbono soup that people like which is attributed to the quantity of *I. gabonensis* kernel powder added to the sample (Bamidele, Ojedokun and Fasogbon 2015). These results are similar to that obtained by Kiin-Kabari and Akusu (2017), which tested formulations of *I. gabonensis* seed (Ogbono) and melon (Egusi) seeds soup premix. They concluded that consumers who do not like very thick soups and low drawability would prefer the formulation with 40:60 Ogbono/Egusi ratio, while consumers who prefer thick soups but low drawability will go for the formulation of 100% "Egusi".

Although oil is the major constituent of the seed, according to Nwokocha and Williams (2014), the defatted seed flour essentially consists of polysaccharides with lower than 5% of non-polysaccharide constituents. Nwokocha and Williams (2014) extracted *I. gabonensis* seed gum from its defatted flour by removing soluble sugars and organic pigments with 95% ethanol, followed by dispersion in distilled water (2% w/w), stirring (6 h), and double centrifugation (2500 rpm for 2h) at 25 ºC. On the other hand, Ndjouenkelu et al. (1996) heated the diluted flour (10 g/250 mL) under reflux and then centrifuged the mixture (2000×g for 30 min), repeating the process with the supernatant (2 times), then precipitated the crude polysaccharide with 85% ethanol and purified the extract by protein removal. Both studies concluded that *I. gabonensis* seed gum has polyelectrolyte properties, as it is an arabinogalactan but also contains a small proportion of neutral sugars and uronic acids (Ndjouenkelu et al. 1996; Nwokocha and Williams 2014). It showed non-Newtonian behaviour at concentrations from 0.2 to 3.0%, having mostly viscous response at concentrations less than 1.0% and elastic response at higher concentrations (Nwokocha and Williams, 2014).

Ogaji, Nan and Hoag (2012) developed a largely physical method for simultaneous extraction of the lipid and polymeric portions of *I. gabonensis*, which was simple, safer, and less expensive than the traditional use of *n*-hexane to extract the lipids. This method was also able to efficiently remove impurities from the gum fraction. The physicochemical properties of the extractives were evaluated, and the results showed similarities in the extractives obtained by this method and those obtained by conventional methods.

Uzomah and Ahiligwo (1999) studied the rheological properties of achi (*Brachystegea eurycoma*) and Ogbono (*I. gabonensis*) seed gums and their potential use as stabilizers in ice cream production. Ogbono seed gum (OSG) cream obtained similar results for quality parameters (maximum overrun, viscosity, shape factor, and meltdown) as the control sample. However, OSG imparted some viscosity to the mixture which resulted in a poor ability to trap and hold air and a poor tendency to resist melting, all of which are characteristics of a satisfactory ice cream. That being said, *I. gabonensis* seed gum was found to be unsuitable as an ice cream stabilizer (Uzomah and Ahiligwo 1999).

It was found that the fat extracted from the kernels can be used for food applications, such as food additive, flavour ingredient, coating fresh citrus fruits and in the manufacture of margarine, oil creams, cooking oil, and defoaming agent. It is also suitable for soap, cosmetics, pharmaceutical products and lather shaving cream (Ejiofor, Onwubuke and Okafor 1987; Ogunsina et al. 2012; Zouè et al. 2013; Okoronkwo et al. 2014; Etong, Mustapha and Taleat 2014; Omoniyi et al. 2017).

Matos et al. (2009) characterized margarine made from *I. gabonensis* kernels from two different origins, with and without lecithin. The major fatty acids found in these margarines were oleic acid (35.5%-37%), palmitic acid (18.5%-19.5%) and lauric acid (13.1%-15.1%). The margarines were more unsaturated than the original oil and could be regarded as an oleic acid source. The ratio between linoleic acid (7.07%) and linolenic acid (0.63%) was lower than 2%, showing it can be used for frying food.

I. gabonenis seed oil has also been studied as a possible biodiesel source (Bello et al. 2011; Adekunle et al. 2016). It was observed that the kernel fat has similar properties to diesel fuel and superior cold flow properties and flash point, which makes it a suitable alternative fuel for diesel engines (Bello et al. 2011). Adekunle et al. (2016) also concluded that the degumming process improves the physicochemical and biodiesel properties of *I. gabonensis* seed fat, as well as other vegetable oils.

4. Other parts

Bark and leaves from *I. gabonensis* have already been traditionally used in Nigeria, Cameroon, and other countries where the fruit is available. Proximate composition of stem bark, leaf, and root bark from *I. gabonensis* reveals them to be nutritionally rich (Table 8).

I. gabonensis leaves have been reported to be used as a self-care plant for icterus treatment, by Benin habitants (Allabi et al. 2011). The appropriation of *I. gabonensis* leaves may be associated with high levels of phytochemicals. Ezeabara and Ezeani (2016) reported that *I. gabonensis* leaves contained 2.44% alkaloids, 1.07% flavonoids, and 2.37% anthraquinone, which can be considered high compared to other parts from the same plant. Awah et al. (2012) compared the free radical scavenging activity and phenolic contents from Nigerian medicinal plants and revealed that *I. gabonensis* had high results when compared to the other samples. However, *I. gabonensis* extract presented relative toxicity to humans in the WST-1-based cytotoxicity and cell viability assays (Awah et al. 2012). This toxicity might be related to the high hydrogen cyanide content of 3.45% (Ezeabara and Ezeani 2016). *I. gabonensis* stem and root barks, instead, do not present relevant levels of hydrogen cyanide, 1.87% and 1.66%, respectively (Ezeabara and Ezeani 2016). Two research studies involving farmers and collectors in Cameroon revealed that *I. gabonensis* stem bark is popular as a traditional medicine. It is reported to treat hernia, yellow fever, dysentery, diarrhoea, malaria, to relieve abdominal pain in women, and as antidote for poisons (Ayuk et al. 1999; Zihiri et al. 2005; Caspa et al. 2015). These effects must be associated with the phytochemicals present in the stem bark. Ezeabara and Ezeani (2016) noted that *I. gabonensis* bark was the most valuable part of the plant, in terms of functional constituents. It consists of the highest percentages of alkaloids (2.78%), flavonoids (1.17%), tannins (1.05%), saponins (0.91%), sterols (0.25%), phenols (0.18%) and anthraquinones (3.17%), compared to the leaf, root bark and raw seed from the same species (Ezeabara and Ezeani 2016).

Zihiri et al. (2005) tested the antiplasmodial activity of ethanol extracts of West African plants, including *I. gabonensis*, and concluded that stem bark extract (10 mg/ml) had a weak antiplasmodial activity against *Plasmodium falciparum* with IC_{50} value of 21.6 µg/ml. However, in a study investigating the analgesic effect, the water extract of the stem bark of *I. gabonensis*, when administered to male mice, was found to protect the mice from pain stimuli (Okolo et al. 1995). Another *in vivo* assay evaluated long-term effects of *I. gabonensis* and other two plants, also known to be hypoglycaemic, on the oxidative status of normal rabbits (Omonkhua and Onoagbe 2012). Oxidative status was determined by measuring activities of superoxide dismutase (SOD) and catalase (CAT), and the concentration of malondialdehyde (MDA). *I. gabonensis* extract had positive effects on increasing serum and tissue antioxidant enzymes, particularly in the pancreas, and on decreasing liver MDA levels (Omonkhua and Onoagbe 2012).

5. Conclusion

As shown in this work, *I. gabonensis* is a good source of nutrients and phytochemicals and its seeds are already widely consumed and processed traditionally. This review enhances our knowledge about the use of other parts of the fruit, especially the pulp, and about improving the existing methods for a safer and more efficient production of value-added products.

I. gabonensis pulp is suitable for juice and wine production, can be also consumed osmose-dried or raw and used as flavourant in the development of other products. It is a vitamin C rich fruit (51-76 mg/100g) having higher ascorbic acid content than mango or orange. Carotenoids, phenolic compounds, and other phytochemical constituents have also been determined, as well as the hypolipidemic effect of *I. gabonensis* juice administration *in vivo*.

I. gabonensis kernel proximate composition revealed its high fat content, as well as a relevant carbohydrate content. *I. gabonensis* kernel oil is considered a “technical” fat because it resists thermo oxidative, hydrolytic, and enzymatic activities due to its fatty acid profile. The presence of steroids, flavonoids, alkaloids, cardiac glycosides, volatile oils, terpenoids, tannins and saponins in *I. gabonensis* kernel extract has been revealed on phytochemical screening and its hepatoprotective, nephroprotective, hypolipidemic effects and its influence on body weight have been confirmed. Potential anti-carcinogenic, anti-lipidemic, analgesic and anti-inflammatory effects of the kernel have been highlighted.

Various methods are employed to process the seed however, all of them have safety issues, when it comes to cracking operation. Various researchers indicated that fermented seeds with specific moisture content, with the appropriate equipment, are easier to crack and kernel loss is reduced. Main products from traditional processing are the sun-dried kernels and the ‘cake’ which is used as a thickener in ‘ogbono soup’, a conventional African food. It was described, that with a more sophisticated process, the fat could be extracted from the kernel powder generating a defated *I. gabonensis* cake. This product can be used as a thickener, stabilizer and as a kind of gum. It is also possible to obtain a crude oil, that can be used not only as edible oil, but in other industries like soup, cosmetic and the pharmaceutical industries.

Furthermore, the production of *I. gabonenis* value-added products could reduce food loss, as this would allow the whole fruit to be used. This will also encourage the consumption of wild fruits and support plant biodiversity. This new approach could ameliorate the diet of rural communities as the *I. gabonensis* fruits are a good source of nutrients and phytochemicals. Commercialization of *I. gabonensis* derived products can also increase the income of the rural communities.

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Table 1: Proximate composition of *Irvingia gabonensis* ripe raw pulp

	FAO, 1968	Onimawo et al., 2003	Stadlmayr et al., 2013	Aina, 1990	Joseph and Aworh, 1991	Mbaeyi and Anyanwu, 2010
Moisture (%)	81.4	80.0	78.8	80.5	80.0	90.47
Ash (%)	1.8	0.8	0.8	-	-	1.41
Fibre (%)	0.4	0.4	0.4	-	-	4.91
Fat (%)	0.2	1.06	1.1	-	-	2.20
Protein (%)	0.9	1.09	1.1	-	-	4.37
Carbohydrate (%)	15.7	16.7	17.8	-	-	4.65
Total Acidity (%)	-	0.112	-	0.31	0.11	-
pH	-	5.84	-	4.7	5.0	6.18
Soluble solids (%)	-	10.0	-	10.5	14.0	9.51

1 Table 2: Phytochemical content (mg/100 g fresh fruit) of *I. gabonensis* ripe raw pulp

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		Reference
Ascorbic Acids	51.00-76.07	FAO, 1968; Onimawo et al., 2003; Stadlmayr et al., 2013; Aina, 1990; Joseph and Aworh, 1991; Olayiwola et al., 2013; Achinewhu, 1983
Carotenoids	1.26 – 2.21	Olayiwola et al., 2013; Aina, 1990
Tannin	54.9	Aina, 1990
Phenolics	382.20	Olayiwola et al., 2013
Vitamin A	280.18*	Mbaeyi and Anyanwu, 2010

4 * Retinol equivalent

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Table 3: Proximate composition of *Irvingia gabonensis* kernel

	Reference														
	Idowu et al., 2013	Onyeike and Acheru, 2002	Elah, 2010	Okoronkwo et al, 2014	Ibezim, 2015	Matos et al., 2009	Ekpe et al., 2007	Ogunsina et al., 2012	Joseph, 1995	Onimawo et al., 2003	Dosumu et al., 2012	Ezeabara and Ezeani, 2016	Giami et al., 1994	Eka, 1980	Ejiofor et al., 1987
Energy (kcal)	684.5	688.00	-	-	-	729,36	-	-	-	-	595.05	-	682	-	-
Moisture Content (%)	4.26	5.93	2.55	3,21	8,28	0,02	5,20	2,55	-	3,36	3.75	11,54	4,1	2,10	11,90
Protein (%)	8.10	8.71	8.90	7,47	8,81	8,52	7,60	8,90	8,70	7,76	21.52	17,43	10,9	8,60	9,24
Fat (%)	67.69	62.80	68.37	68,81	69,34	68,24	66,60	68,37	66,50	65,46	55.09	9,81	64,2	70,80	51,32
Fiber (%)	5.88	-	-	4,38	1,25	-	1,90	-	-	10,23	-	4,18	3,4	1,40	0,86
Ash (%)	3.35	0.63	2.32	8,71	4,52	2,93	9,50	2,32	-	2,26	16.35	4,66	2,2	6,80	2,46
Carbohydrate (%)	10.72	21.93	18.67	-	11,39	20,28	-	18,67	-	10,93	3.29	52,40	15,2	14,10	26,02

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Table 4: Micronutrient content (mg/100 g) of *I. gabonensis* kernel

	Reference		
	Onyeike and Acheru, 2002	Ayivor et al., 2011	Dosumu et al., 2012
Lead	0.054	-	-
Iron	0.315	19.374	10.101
Copper	0.139	5.722	2.346
Zinc	0.285	5.786	4.386
Potassium	15.600	0.723	612.55
Sodium	2.020	4.383	59.99
Phosphate	16.800	-	-
Sulphate	0.008	-	-
Chloride	259.000	42.639	-
Aluminium	-	3.567	-

Table 5: Physicochemical parameters of *I. gabonensis* kernel oil

	Reference						
	Onyeike and Acheru, 2002	Joseph, 1995	Ogunsina et al., 2012	Okoronkwo et al., 2014	Matos et al., 2009	Zoué et al., 2013	Etong et al., 2014
Chemical Parameters							
Oil yeld (%)	62.80	66.5	68.37	68.81	62.67	69.76	22.50
Acid value (mg KOH/g)	24.7	-	-	3.18	12.94	4.67	9.40
Saponification value (mg KOH/g)	701	219.2	256.5	230.95	199.50	233.75	187.90
Peroxide value (meq O_2/kg fat)	0.04	1.98	0.5	2.67	1.9	3.33	1.80
Iodine value (g I_2/ 100g fat)	21.5	4.2	8.2	13.40	4.3	32.43	4.50
Free fatty acids (%)	1.19	0.30	2.72	1.59	4.61	2.33	4.70
Unsaponifiable matter (%)	1.70	0.12	-	-	-	1.50	1.50

Physical Parameters							
State at room temperature	Semi liquid	-	Solid	-	-	-	Solid
Specific gravity	0.89	0.85	-	-	-	-	0.88
Smoke point (°C)	-	213.0	-	147.57	-	-	78
Cloud point (°C)	-	35.0	-	41.83	-	-	-
Flash point (°C)	-	-	-	335.33	-	-	-
Fire point (°C)	-	-	-	340.67	-	-	-
Setting point (°C)	26.3	-	-	-	-	-	25.30
Melting/freezing point (°C)	56.0	39.5	-	32.47	-	-	13
Colour	Golden yellow	-	White	-	-	-	Grey yellow

Table 6: Mean values (%) of the fatty acid profile of *I. gabonensis* kernel oil

	Reference							
	Matos et al., 2009	Nangue et al., 2011	Silou et al., 2011	Ogunsina et al., 2012	Zoué et al., 2013	Etong et al., 2014	Yamoneka et al., 2015	Lieb et al., 2018
Capric acid (C 10:0)	1.34	1.54	0.82	-	0.25	-		1.3
Lauric acid (C 12:0)	39.37	40.70	33.18	27.63	39.35	39.40		37.6
Myristic acid (C 14:0)	50.92	49.05	55.74	61.68	20.54	20.50		51.3
Palmitic acid (C 16:0)	4.97	5.06	5.85	7.49	10.39	10.30		5.4
Stearic acid (C 18:0)	0.73	2.38	0.76	0.81	11.46	11.40		1.0
Oleic acid (C 18:1)	1.97	0.49	1.35	2.12	6.99	6.90		2.3
Linoleic acid (C 18:2)	0.48	-	0.44	0.27	0.01	6.40		-
Linolenic acid (C 18:3)	0.00	-	-	-	6.44	-		-
Arachidic acid (C 20:0)	-	-	-	-	4.52	-		-
Saturated fatty acid	97.33	98.73	-	97.61	86.56	-		-
Monosaturated fatty acid	1.97	-	-	2.21	6.99	-		-
Polyunsaturated fatty acid	0.48	0.49	-	0.27	6.45	-		-
n-6/n-3 ratio	-	-	-	-	1.55	-		-

Table 7: Phytochemical constituents of *I. gabonensis* kernel

	Value	Reference
DPPH antiradical assay	177.22% (IC_{50})	Arogba and Omede, 2012
FRAP* assay	431.58 mg of catechin equiv/g	Agbor et al., 2005
	65.43 mM Fe^{+2} (IC_{50})	Arogba, 2014
Lipid peroxidation assay	375.38% (IC_{50})	Arogba, 2014
Nitric oxide assay	106.12% (IC_{50})	Arogba, 2014
TPC*	2.6 mg/100g	Giami et al., 1994
	10.74 mg/g	Agbor et al., 2005
	1.15 mg/g dw	Arogba, 2014
TFC*	077 mg QUE/g dw	Arogba, 2014
TAC*	0.67 ng cyanidin chloride/g dw	Arogba, 2014
TTC*	1.25 mg catechin/g dw	Arogba, 2014
TCC*	3.6 mg/100g	Giami et al., 1994
Ascorbic acid	6.2 mg/100g	Giami et al., 1994

*(FRAP - Ferric reducing antioxidant power; TPC – Total Phenolic Compounds; TFC – Total Flavonoid Compounds; TAC – Total Anthocyanin Compounds; TTC – Total Tannin Compounds; TCC – Total Carotenoid content)

1 Table 8: Proximate composition (%) of *I. gabonensis* stem bark, leaf and root bark (Ezeabara and Ezeani 2016)

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	Stem bark	Leaf	Root bark
Moisture	9.43	10.83	8.91
Dry matter	90.58	89.17	91.09
Ash	7.72	9.61	6.58
Fibre	11.38	15.34	8.69
Fat	2.78	1.86	1.45
Protein	5.28	14.78	5.92
Carbohydrates	63.43	47.58	68.44

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